Debris Prediction System

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DEBRIS PREDICTION SYSTEM

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DEBRIS PREDICTION SYSTEM

This writeup describes the technical basis for a computer program (DEBMOD) that predicts weight of potential debris from harvesting and thinning. The debris comes from foliage, branches, unmerchantable bole tips, cull trees, and merchantable tree defect (fig. 1). Using timber inventory data, the program estimates debris for individual trees and sums up weights on a per acre basis. Inputs are from the USDA Forest Service Northern Region's Stage I Timber Stand Exam and include:

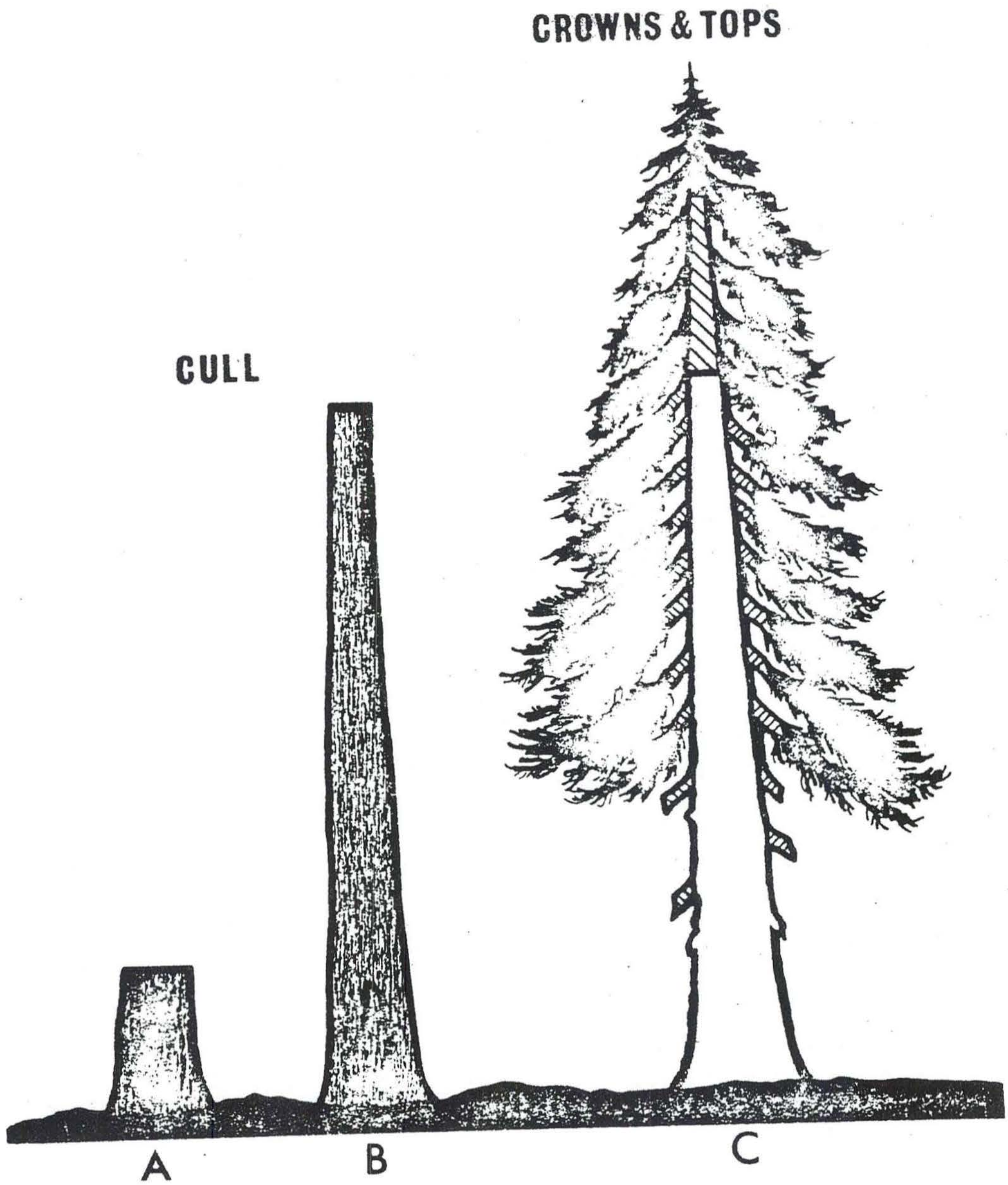
- Species
- D.b.h.
- Tree height
- Live crown ratio
- Crown class
- Tree history class
- Downed or standing tree code
- Basal area factor
- Number of sample points

Outputs are available for three options:

OPTION 1: Tons per acre for material less than 3 inches in diameter, material 3 inches and greater in diameter, and cull material. This option should be the most frequently used, especially for appraising fuels and fire behavior.

OPTION 2: Tons per acre for foliage; branchwood and tops by size classes of less than 0.25 inch, 0.25 to 1 inch, 1 to 3 inches, and 3+ inches; cull material for live, dead sound, and dead unsound trees. This option gives the maximum detail which will be unnecessary for most applications.

OPTION 3: Cubic feet per acre for top and branchwood material 3 inches and larger and for cull material from live trees, dead sound trees, and dead nonsound trees. This option is primarily for evaluating fiber potential for utilization, using cubic foot units.



DEBRIS IS GENERATED FROM DIFFERENT PARTS OF A TREE

CULL (A) For healthy trees (tree history 1), cull weight is computed by applying cull weight factors to the bole.

(B) For live cull, nonsound, and dead trees (tree history 2 through 8), cull weight is the total weight of the bole.

CROWNS AND TOPS (C) The <3-inch class includes all foliage, live and dead branchwood <3-inch diameter, and the tip portion of the bole less than 3 inches.

<3

>3

The 3-inch and larger class includes all live and dead branchwood and unmerchantable tips 3 inches and larger.

Figure 1.

Available printed information describing operation and application of the debris prediction system includes:

1. Program documentation by Cameron Johnston, Northern Forest Fire Laboratory, Drawer G, Missoula, Montana. Describes input codes and control, structure, and setup of Program.

2. "Users Guide to the Northern Region Debris Prediction System" (copies available from Division of Fire Management, Northern Region and the Northern Forest Fire Laboratory.) Describes, for field managers, how to obtain debris printouts and use the information.

The debris prediction system is primarily based on results of a study on crown weights and size distribution conducted at many locations in western Montana and northern Idaho by the Fuel Science Project, Northern Forest Fire Laboratory (Brown 1976). Additional data and study results of others were utilized for estimating weights of unmerchantable tips and cull. Species in the debris prediction system and for which data were collected include:

Douglas-fir	Ponderosa pine	Western redcedar
Engelmann spruce	Subalpine fir	Western white pine
Grand fir	Western hemlock	Whitebark pine
Lodgepole pine	Western larch	

The prediction equations for lodgepole pine are actually used in predicting debris for whitebark pine. Although crown data were gathered for whitebark pine, the sample trees were stunted from exposure along alpine ridges. Lodgepole pine was thought to be a good substitute for whitebark pine. Besides the above species, the Program also accepts mountain hemlock which is equated to western hemlock and limber pine which is equated to whitebark pine.

Debris weights are calculated separately for crowns, unmerchantable tips, and cull and are explained separately here.

CROWNS

D.b.h. Less Than 1-inch

For trees equal to or less than 1-inch d.b.h. (seedlings), live crown weight is calculated as a function of tree height (table 1). If height is not inventoried, the following average crown weights are employed:

Species	Weight (lbs)
Subalpine fir, grand fir, Engelmann spruce, Douglas-fir	2.3
Ponderosa pine, western white pine, western redcedar	1.8
Lodgepole pine, western larch, western hemlock	.9

Dead crown weight for seedlings is negligible, thus is assumed to be zero. Data for seedling and larger trees were analyzed separately to improve accuracy in weight estimate.

Some explanation of terms in the tables include:

1. Mean square is the error mean square from regression. For logarithmic functions, the mean square is based on the sum of squared deviations computed using arithmetic units rather than logarithms.
2. SE is the standard error of estimate, $\sqrt{\text{ERROR MEAN SQUARE}}$.
3. Tree height includes a 1-foot stump.

D.b.h. Greater Than 1-inch

Relationships based on data from dominant and codominant crown classes are applied to all crown classes except for larch, lodgepole pine, ponderosa pine, and Douglas-fir. For these species, crown weights are adjusted downward for intermediate and suppressed crown classes.

Live crown weights are determined from equations in table 2. Equations containing d.b.h., as well as height and crown ratio as independent variables, are used for calculations when height or crown ratio appear on the inventory record. Otherwise, equations containing only d.b.h. are used. Dead crown weights are determined from equations having d.b.h. as the only independent variable (table 3). To avoid ridiculous estimates from overextending equations, any d.b.h. exceeding 40 inches is set equal to 40 inches.

Live and dead crown weights are partitioned into needles and branchwood by size classes using accumulative proportions of needles and branchwood. For live crowns of trees greater than 1-inch d.b.h., the accumulative proportions are designated by PROP 1 for needles, PROP 2 for needles + 0- to 0.25-inch branchwood, PROP 3 for needles + 0- to 0.25-inch + 0.25- to 1-inch branchwood, and PROP 4 for needles + 0- to 0.25-inch + 0.25- to 1-inch + 1- to 3-inch branchwood (table 4). Except for the smallest size class, actual proportions of crown components are obtained by subtraction of accumulative proportions. For example, living crown proportions are:

Fraction of needles	= PROP 1
Fraction of 0- to 0.25-inch branchwood	= PROP 2 - PROP 1
Fraction of 0.25- to 1-inch branchwood	= PROP 3 - PROP 2
Fraction of 1- to 3-inch branchwood	= PROP 4 - PROP 3, or
if no PROP 4, then	= 1.0 - PROP 3
Fraction of 3+-inch branchwood	= 1.0 - PROP 4

For live crowns of seedlings, actual proportions of needles and branchwood were averaged for all sample trees and are shown in table 5.

For dead crowns, the accumulative proportions are designated by PROP 1 for 0- to 0.25-inch branchwood and PROP 2 for 0- to 0.25-inch + 0.25- to 1-inch (table 6). Like live crowns, the actual proportions are determined by subtraction. The 1- to 3-inch class is 1.0 minus PROP 2.

Adjustment for Intermediate and Suppressed Crown Classes

Crown weights of trees having intermediate crown classes were studied for ponderosa pine, Douglas-fir, grand fir, and cedar. For ponderosa pine and Douglas-fir, crown weight per tree varied significantly between intermediate and dominant-codominant crown classes. For grand fir and cedar, crown weight per tree was not significantly different between crown classes. These results suggested that crown weight estimates for intolerant species should account for crown class differences.

In the debris prediction system, live and dead crown weights for intermediate and suppressed crown classes of ponderosa pine and Douglas-fir are calculated from the following equations:

Species	n	r^2	Equation
Ponderosa pine, live crown	15	0.90	w = EXP(-0.7572 + 2.2160 lnd)[1/]
Ponderosa pine, dead crown	15	.81	w = EXP(-2.5176 + 2.5100 lnd)
Douglas-fir, live crown	15	.90	w = EXP(0.1508 + 1.8621 lnd)[1/]
Douglas-fir, dead crown	15	.89	w = EXP(-1.9280 + 2.3530 lnd)

Based on data for ponderosa pine, crown weight for intermediate and suppressed lodgepole pine and larch are estimated as the following fractions of dominant-codominant crown weight:

D.b.h.	Fraction
Less than or equal to 7.5 inches	0.50
Greater than 7.5 inches	.60

1/ Mean square/2 included in regression constant A to provide best log fit.

Proportions of needles and branchwood are determined using the functions in tables 4 and 6, except for the following equations that apply to ponderosa pine live crowns:

PROP 1 = 0.6501 EXP(-0.1544d)

PROP 2 = 0.8435 EXP(-0.1665d)

PROP 3 = 1.0865 EXP(-0.0833d)

UNMERCHANTABLE TIPS AND SMALL TREES

Small Trees

Small trees are considered as any tree having a d.b.h. equal to or less than 4.0 inches. The debris prediction system computes the total bole weight (wood plus bark) of small trees based on the crown study by Brown (table 7).

Unmerchantable Tips

Unmerchantable tip weights are determined using four sources of information: unmerchantable tip volume (inside bark) equations, wood densities, ratios of bark thickness-to-stem thickness, and bark densities. Unmerchantable tip volumes are calculated using equations developed by Faurot[2/] for ponderosa pine, Duglas-fir, larch, and lodgepole pine (table 8). A comparison of volumes among the four species showed small differences. Thus, the equations for Douglas-fir, which provide intermediate volumes among the four species, were chosen to represent species not studied by Faurot. One exception is that whitebark pine is represented by lodgepole pine.

[2/] Faurot, James L. Tables for estimating stem residues study for ponderosa pine, western larch, Douglas-fir and lodgepole pine in western Montana. USDA For. Serv., Intermt. For. & Range Exp. Stn. Pap. (in process)

To maintain reasonable estimates for trees beyond the range of study data, d.b.h. is restricted at 20 inches for lodgepole pine and 24 inches for all other species. Height is restricted at 120 feet for lodgepole pine and 130 feet for other species.

The debris prediction system furnishes output for merchantable top diameter limit options of 3, 4, and 6 inches which must be specified by users. The Program also contains functions for merchantable top diameter limits of 2, 7, and 8 inches and could be easily modified to furnish output for these limits.

Tip volumes are converted to weight using wood densities (table 9) taken for USDA Forest Service (1955) and USDA Forest Products Laboratory (1965).

Bark weight was determined by multiplying ratios of bark weight-to-wood weight (R) times estimates of wood weight. The ratios R were calculated from:

$$R = \rho_b\left(\frac{\pi d_o^2 \ell}{4} - \frac{\pi d_i^2 \ell}{4}\right) \Big/ \rho_s\left(\frac{\pi d_i^2 \ell}{4}\right) = \frac{\rho_b}{\rho_s}\left(\frac{d_o^2}{d_i^2} - 1\right) \tag{1}$$

where

ρ_b = density of bark, lbs/ft^3

ρ_s = density of wood, lbs/ft^3

d_o = diameter outside bark, ft

d_i = diameter inside bark, ft

ℓ = length of cylindrical tree piece, ft.

Data on diameters inside and outside bark were supplied by Faurot and James Brickell, USDA For. Serv., Intermt. For. & Range Exp. Stn. Measurements from along the entire length of trees were used in the analysis. Values of R varied substantially. Average R was greater for tip sections than entire trees; however, values for entire trees were used to represent tips because

the values seemed more reliable than those from the limited data for tip sections. Bark densities were obtained from Smith and Kozak (1971). Values used to calculate the R ratios are in table 9.

Missing Height Records

When height is missing from a tree inventory record, it is estimated using height-d.b.h. equations in table 10. These equations are based on the crown weight study by Brown (1976). Weight calculations for both small trees and unmerchantable tips depend on height estimates when height is not inventoried.

Size Class Fractions for Tips and Small Trees

Unmerchantable tips and small tree weights are partitioned into 0- to 1-inch, 1- to 3-inch, and 3+-inch size classes using fractions based on volume estimates.

Because the amount of tip and small tree material 0 to 0.25 inch in diameter is very small, this size class is not computed separately but is lumped into the 0- to 1-inch class. The size class fractions, table 11, are averages based on data for all species. Data for all species were combined after finding that variation of the fractions among species were small.

Volumes were calculated assuming cones for tip pieces and frustrums of cones for other pieces. Diameters and piece lengths for solving cone and frustrum volume formulas were measured in the crown study (Brown 1976).

CULL BOLEWOOD

Predicting weight of cull bolewood is difficult to do accurately. In the debris prediction system, estimates of cull are intended to be the maximum expected. Some cull material is removed from the woods or left standing for wildlife habitat. To improve estimates of cull, experience with local harvesting practices is needed to reduce the maximum cull estimate by the amount of cull material removed from the woods or left standing.

Tree history code recorded for each inventoried tree controls the method of cull weight estimation. For live and dead sound trees, cull weight is computed in this sequence:

1. Calculate total tree volume using equations in table 12 from Stage's (1973) prorosis model for stand development (TREMØD01 PRØGRAM).

2. Convert total bole volume to weight using wood densities from table 9.

3. Calculate merchantable bole weight by subtracting tip weight from total bole weight.

4. For live merchantable trees (tree history 1), cull weight is calculated by multiplying defect fractions times merchantable bole weight. The defect fractions (table 13) are averages of data gathered on the Clearwater and Coeur d'Alene National Forests in a study by the Northern Region. For live cull trees (tree histories 2 and 8), the entire bole weight is considered as cull.

5. For dead sound trees (tree histories 4, 5, and 6), 50 percent of the merchantable bole weight is taken as cull. By definition, 50 percent or more of dead sound trees should be sound and could be removed as merchantable wood. Computing 50 percent of the bole weight as cull is simply using the definition of dead sound trees to make cull estimates as realistic as possible.

6. Bark weight is calculated and added to the estimates of cull bole weight. Bark weight is calculated by multiplying ratios of bark weight-to-wood weight (table 9) times cull bole weight.

Nonsound trees (tree history 7) presented an additional difficulty in estimating volume because many nonsound trees exist as broken tree snags,, thus making total tree volume equations inappropriate. To determine volume of a broken off tree, we assumed that a frustrum of a right cone approximates its volume.

Comparing volumes from total tree volume equations and the cone frustrum equation showed that for whole trees the cone frustrum equation considerably overestimates volume. To avoid using the frustrum of a cone equation where the total tree volume equations provide reasonable estimates, the following rule was established:

Use the frustrum of a cone formula if inventoried height is equal to or less than the following fractions of expected height:

Species	*Fraction*
Grand fir, white pine	*0.50*
Larch	*0.55*
Cedar	*0.65*
Others	*0.35*

Otherwise, volume is calculated using total tree volume equations.

Expected height is calculated as a function of d.b.h. using the following equations developed from permanent sample plots in northern Idaho:

Species	Equation	
White pine, cedar, larch, hemlock	$H = EXP(5.4979 - 14.6749/(DBH + 1)) + 4.5$	(2)
Others	$H = EXP(4.8569 - 9.3695/(DBH + 1)) + 4.5$	(3)

Volume for frustrum of a cone is calculated from:

$$V = 0.001498\ h(d_1^2 + d_1 d_2 + d_2^2) \tag{4}$$

where

V = volume of stemwood without bark, ft^3

$d_1 = DBH + 0.5$, in. (5)

$d_2 = DBH - 0.11h + 0.5$, in. (6)

h = inventoried height, ft.

Since diameters outside bark are parameters in calculating volume using the frustrum of a cone formula, the solution includes bark. It was necessary to eliminate bark volume in equation (4) because bark weight is computed in another portion of the debris prediction program. Bark volume was eliminated by dividing the standard formula for a frustrum of a cone by 1 plus 0.214. An average bark-to-stem ratio of 0.214 was determined from bark and stem thickness data by Brickell (see Tip Section).

The diameters in equation (4) were scaled from d.b.h. to top of snag and ground level using average taper factors of 0.52 inch of diameter per foot of height for below d.b.h. and 0.11 for above d.b.h. The taper factors were also determined from data by Brickell.

TREE HISTORY MODIFICATIONS

Tree history modifications of potential debris have been discussed for cull weight. Quantities of foliage, branches, tops, and bark are also modified depending on tree history. In the debris prediction program, the modifications are executed by multiplying an array of fractions (table 14) times the complete debris potential. One exception is defect from tree history 1 trees which is computed outside of this array.

The modifications in table 14 for bark, foliage, and branches are based on averaged data and information contained in the section on "Guides for Establishing Time Since Mortality" of the Northern Region's 1973 Stage I Field Instructions.

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TABLE 1.--*Equations for live crown weight of trees 1-inch and less in d.b.h.*

Species	R^2	Mean square	n	Function
Grand fir	0.79	3.138	12	$w = 0.4284(h)$
Western white pine	.97	.190	13	$w = 0.3292(h)$
Ponderosa pine	.81	1.235	12	$w = 0.3451(h)$
Lodgepole pine	.96	.220	12	$w = 0.03111(h^2)$
Western redcedar	.90	1.908	12	$w = 0.04833(h^2)$
White bark pine	.93	.085	10	$w = 0.070 + 0.02446\ h^2$
Douglas-fir	.83	1.156	11	$w = e^{(-4.212 + 2.7168 \ln h)}$
Western hemlock	.91	2.221	12	$w = e^{(-5.126 + 2.563 \ln h)}$ 1/
Engelmann spruce	.94	7.290	12	$w = e^{(-3.932 + 2.571 \ln h)}$ 1/
Alpine fir	.90	1.343	13	$w = e^{(-3.335 + 2.303 \ln h)}$ 1/
Western larch	.80	1.230	12	$w = 0.1128(h) + 0.00813(h^2)$

1/ Mean square/2 included in regression constant A to provide best log fit.

TABLE 2.--*Equations for live crown weight of trees greater than 1-inch d.b.h.*

ɔecies	R^2	Mean square	n	$\left(\frac{SE}{\bar{Y}}\right)100$	Range[1] in DBH	Equations[2]
ınd fir	0.95	26,104	35	57	1-40	w = EXP(1.3094 + 1.6076*lnd)[3]
ɔalpine	.95	276	16	25	1-13	$w = 0.1862\ d^2R + 1.066$
r	.84	947		46		$w = 7.345 + 1.255d^2$
ıgepole	.88	600	45	22	1-16	$w = 0.02238d^3 + 0.1233d^2R - 2.00$
ıe	.88	1,065		30		w = EXP(0.1224 + 1.8820*lnd)[3]
rch	.96	3,684	45	38	1-35	w = EXP(0.4373 + 1.6786*lnd)[3]
ʒelmann ruce	.96	11,469	29	36	1-29	w = EXP(1.0404 + 1.7096*lnd)[3]
ıglas-r	.95	4,712	41	28	1-34	$w = 27.94 - 0.008695d^2h + 0.02839d^2c$, for d >15 in. If R <5, set R = 5.
	.93	21,615		64		w = EXP(1.1368 + 1.5819*lnd)[3], for d <17 inches
	.85	13,455		48		$w = 1.0237d^2 - 20.74$, for d $\geq$17 inches
stern	.98	809	27	15	1-32	$w = 0.3729d^2 + 0.2840dc - 0.005525d^2c - 4.501$
mlock	.98	4,605		36		w = EXP(1.7502*lnd + 0.7218)
ite	.97	956	44	24	1-43	$w = 0.09470d^2R$
ne	.95	3,279		45		w = EXP(0.7276 + 1.5497*lnd)[3]
dar	.97	7,965	34	46	1-37	w = EXP(1.7273*lndR - 2.8086)
	.96	10,070		52		w = EXP(0.8815 + 1.6389*lnd)
nderosa	.97	37,563	40	36	1-34	w = EXP(2.2812*lnd + 1.5098*lnR - 3.0957)[3]
ne	.95	82,569		53		w = EXP(0.2680 + 2.0740*lnd)[3]
ite bark	.88	600	45	22	1-16	$w = 0.02238d^3 + 0.1233d^2R - 2.00$
ne	.88	1,065		30		w = EXP(0.1224 + 1.8820*lnd)[3]

1/ Range in DBH for sample trees.

2/ w = weight, lbs; d = DBH, in; h = tree height, ft; c = living crown length, ft; = crown ratio expressed as (crown length/total tree height)10.

3/ These equations are of the form lny = a + blnX + (mean square error/2). The tter term corrects for bias in transforming logs. The intercept term was adjusted by ean square/2) when the summation of predicted minus observed values in arithmetic its showed less bias with the correction term than without it.

TABLE 3.--*Equations for dead crown weights of trees greater than 1-inch d.b.h.*

Species	R^2	Mean square	n	$\left(\frac{SE}{Y}\right)100$	Range[1/] in DBH	Equations[2/]
Douglas-fir	0.91	1,431	21	50	1-34	$w = 0.01094d^3$
Larch[3/]						$w = 0$
Lodgepole pine						$w = (0.026d - 0.025)*(\text{live wt})$, for $d \leq 10$ inches $w = 0.235*(\text{live wt})$, for $d > 10$ inches
Ponderosa pine	.87	4,590	26	79	1-34	$w = EXP(2.8376*\ln d - 3.7398)$
Cedar	.98	91.2	20	23	1-27	$w = 0.01063d^3$
Subalpine fir	.91	67	16	102	1-13	$w = EXP(4.0365*\ln d - 6.5431)$, for $d \leq 16$ inches $w = 0.31*(\text{live wt})$, for $d > 16$ inches
Western hemlock	.84	297	20	227	1-21	$w = EXP(3.3664*\ln d - 6.6768)$
White pine	.80	184	18	135	1-25	$w = EXP(2.6076*\ln d - 4.3970)$
Engelmann spruce	.87	992	14	165	1-23	$w = EXP(3.6172*\ln d - 6.6860)$
Grand fir	.93	487	22	62	1-20	$w = EXP(3.5638*\ln d - 5.3154)$, for $d \leq 18$ inches $w = 0.38*(\text{live wt})$, for $d > 18$ inches

1/ Range in DBH for sample trees.

2/ w = weight, lbs; d = DBH, in; h = tree height, ft; c = living crown length, ft

3/ Insignificant quantities of dead branches present on larch.

TABLE 4.--*Accumulative proportions of needles and branchwood by size classes for live crowns of trees greater than 1-inch d.b.h.*

Species	Function	R^2	Conditions
Engelmann spruce	PROP 1 = 0.5783 EXP(-0.03250d)	0.97	If d >40.0 inches, PROP 1 = 0.158, PROP 2 = 0.277, PROP 3 = 0.423
	PROP 2 = 0.8519 EXP(-0.02811d)	.97	
	PROP 3 = 1.03781 - 0.01537d	.95	If d $\leq$2.9 inches, PROP 3 = 1.0
Western hemlock	PROP 1 = 0.5474 EXP(-0.03697d)	.96	IF d >40.0 inches, PROP 1 = 0.125, PROP 2 = 0.183, PROP 3 = 0.361
	PROP 2 = 0.8352 EXP(-0.03802d)	.97	
	PROP 3 = 1.0781 EXP(-0.02735d)	.94	If d $\leq$2.9 inches, PROP 3 = 1.0
Western white pine	PROP 1 = 0.5497 EXP(-0.0345d)	.95	
	PROP 2 = 0.9138 -0.0978 $\sqrt{d}$	.91	
	PROP 3 = 1.0564 EXP(-0.0181d)	.87	If d $\leq$3.9 inches, PROP 3 = 1.0
Ponderosa pine	PROP 1 = 0.5578 EXP(-0.04754d)	.89	If d $\geq$31 inches, PROP 2 = PROP 1 + 0.01
	PROP 2 = 0.6254 EXP(-0.05114d)	.89	
	PROP 3 = 0.9850 EXP(-0.03102d)	.85	If d $\leq$1.0 inch, PROP 3 = 1.0
	PROP 4 = 1.0830 -0.01306d	.70	If d $\leq$6.5 inches, PROP 4 = 1.0
Lodgepole pine	PROP 1 = 0.4933 -0.01167d	.76	
	PROP 2 = 0.7767 -0.01464d	.70	
	PROP 3 = 1.0494 -0.01402d	.55	If d $\leq$3.9 inches, PROP 3 = 1.[illegible]
Grand fir	PROP 1 = 1/(1.5916 + 0.05294d)	.94	If d >36.0 inches, PROP 1 = 0.286, PROP 2 = 0.378, PROP 3 = 0.488
	PROP 2 = 1/(1.1495 + 0.04165d)	.96	
	PROP 3 = 1.0267 -0.01495d)	.94	If d $\leq$2.9 inches, PROP 3 = 1.0
Western redcedar	PROP 1 = 0.6174 EXP(-0.02326d)	.98	
	PROP 2 = 0.7562 EXP(-0.02411d)	.98	
	PROP 3 = 1.0602 EXP(-0.02226d)	.98	If d $\leq$2.9 inches, PROP 3 = 1.0
Western larch	PROP 1 = 0.3468 EXP(-0.04343d)	.93	
	PROP 2 = 0.7450 EXP(-0.03622d)	.93	
	PROP 3 = 1.05448 EXP(-0.02130d)	.91	If d $\leq$2.9 inches, PROP 3 = 1.0
	PROP 4 = 0.9223 + 0.7197/d	.07	If d $\leq$11.0 inches, PROP 4 = 1.0
Douglas-fir	PROP 1 = 0.4840 EXP(-0.02102d)	.95	If d >36.0 inches, PROP 1 = 0.227, PROP 2 = 0.315, PROP 3 = 0.465
	PROP 2 = 0.7289 EXP(-0.02332d)	.95	
	PROP 3 = 1.0342 -0.01584d	.95	If d $\leq$2.9 inches, PROP 3 = 1.0
	PROP 4 = 1.0221 -0.001821d	.43	If d $\leq$14.0 inches, PROP 4 = 1.0
Subalpine fir	PROP 1 = 0.5966 EXP(-0.04247d)	.74	
	PROP 2 = 0.8643 EXP(-0.03733d)	.72	
	PROP 3 = 1.0221 -0.01083d	.50	If d $\leq$2.9 inches, PROP 3 = [illegible]

TABLE 5.--*Needle and branchwood proportions of live crowns for trees equal to or less than 1-inch d.b.h.*

Species	Size class		
		Branchwood	
	Needles	0 to 0.25	0.25 to 1
Spruce, subalpine fir, cedar, grand fir, hemlock	0.62	0.26	0.12
Douglas-fir, white pine, lodgepole pine	.52	.27	.21
Ponderosa pine	.57	.14	.29
Larch	.40	.42	.18

TABLE 6.--*Accumulative proportions of branchwood by size classes for dead crowns*

Species	Function	R^2	Conditions
Engelmann spruce	PROP 1 = $1.4657d^{(-0.6454)}$	0.77	If d <1.8 inches, PROP 1 = 1.0
	PROP 2 = 1/(0.8470 + 0.01678d)	.34	If d <10.0 inches, PROP 2 = 1.0
Western hemlock	PROP 1 = 1.9608 EXP(-0.2064d)	.79	If d <4.0 inches, PROP 1 = 1.0
	PROP 2 = 1.0/(0.2772 + 0.06141d)	.24	If d >28.0 inches, PROP 1 = 0.005
			If d <12.0 inches, PROP 2 = 1.0
Western white pine	PROP 1 = $1.0077d^{(-0.4556)}$	.49	
	PROP 2 = 1.0291 - 0.004964d	.12	If d <7.0 inches, PROP 2 = 1.0
Ponderosa pine	PROP 1 = 1.4114/d - 0.04345	.60	If d >30.0 in., PROP 1 = 0.004
	PROP 2 = 1.0621 - 0.03342d	.69	If d >30.0 in., PROP 2 = 0.06
Lodgepole pine	PROP 1 = $1.3527d^{(-0.7585)}$	.95	If d >20.0 in., PROP 1 = 0.139
	PROP 2 = 2.7979 EXP(-0.1257d)	.77	If d >20.0 in., PROP 2 = 0.226
			If d <9.0 in., PROP 2 = 1.0
			If d <1.5 in., PROP 1 = 1.0
Grand Fir	PROP 1 = 1.4336 EXP(-0.1816d)	.77	If d <3.0 in., PROP 1 = 1.0
	PROP 2 = 1.2623 EXP(-0.03470d)	.17	If d >27.0 in., PROP 1 = 0.01
			If d <8.0 in., PROP 2 = 1.0
Western redcedar	PROP 1 = -0.01578 + (1.4673/d)	.87	If d <1.5 in., PROP 1 = 1.0
	PROP 2 = 1.4534 EXP(-0.05395d)	.66	If d <8.0 in., PROP 2 = 1.0
Douglas-fir	PROP 1 = 0.08355 + (1.5893/d)	.81	If d <1.8 in., PROP 1 = 1.0
	PROP 2 = 1.5673 EXP(-0.05232d)	.56	If d <9.0 in., PROP 2 = 1.0
Subalpine fir	PROP 1 = $1.2105d^{(-0.5650)}$	.62	If d <1.5 in., PROP 1 = 1.0

TABLE 7.--*Weight of boles (wood plus bark) for trees equal to or less than 4 inches d.b.h.*1/

Species	Equation
Grand fir	$w = 0.62 + 0.8024d^2 + 0.1724d^3$
Western redcedar	$w = 1.4364d + 0.3326d^3$
Western white pine	$w = 1.15 + 0.5297d^3$
Douglas-fir	$w = 0.74 + 1.5907d^2$
Engelmann spruce	$w = EXP(0.7839 + 1.2900 \ln d)$
Ponderosa pine	$w = 1.1029d^2 + 0.56$
Lodgepole pine	$w = 1.49 - 2.3876d + 2.2973d^2$
Western hemlock	$w = 0.31 + 0.8334d + 0.06819d^2h$
Western larch	$w = 0.65 + 0.1004d^2h$
Subalpine fir	$w = 0.28 + 0.02692d^2h + 0.1912dh$

1/ w = weight, lbs; d = d.b.h., in; h = height, ft.

TABLE 8.--*Regression coefficients for an equation of the form* $\log V = a + b_1(\log D) + b_2(\log D)(\log H)$ *that estimates unmerchantable tip volumes inside bark*[1/]

Regression coefficients	Tip diameter inside bark 2	3	4	5	6	7	8
			PONDEROSA PINE				
a	-0.4606	0.2991	0.8425	1.2640	1.8058	2.2951	2.5923
b_1	-2.0969	-2.2226	-2.1364	-2.2081	-2.6864	-3.0613	-3.2637
b_2	.7331	.6997	.5907	.5898	.7197	.8008	.8658
			LODGEPOLE PINE				
a	-.3657	.3763	.8605	1.2906	1.8684	2.3623	2.7091
b_1	-2.4696	-2.4963	-2.4829	-2.5269	-2.9716	-3.4511	-3.5020
b_2	.8675	.7796	.7412	.7210	.8103	.9437	.9056
			DOUGLAS-FIR				
a	-.5748	.2284	.7769	1.2797	1.6901	2.0216	2.4528
b_1	-1.7970	-2.1354	-2.1915	-2.3743	-2.5815	-2.6844	-3.0851
b_2	.6340	.6885	.6476	.6614	.7050	.7128	.8253
			WESTERN LARCH				
a	-.2184	.5749	1.2042	1.7165	2.1151	2.5125	2.8962
b_1	-2.6178	-3.0534	-3.3550	-3.4430	-3.4318	-3.6729	-4.0237
b_2	.9008	1.0075	1.0616	1.0228	.9581	1.0132	1.1191

[1/] V = volume, ft^3; D = d.b.h., in; H = height, ft.

TABLE 9.--*Wood densities, bark densities, bark volume-to-stem volume ratios, and bark weight-to-stem weight ratios used in estimating weights of unmerchantable bole tips*

Species	Wood density	Bark density	Bark volume[1/] / Stem volume	Bark weight[2/] / Stem weight
	Lb/ft³	*Lb/ft³*		
Ponderosa pine	25.0	21.8	0.24	0.209
Lodgepole pine	25.6	26.5	.11	.114
Western white pine	23.7	26.2	.21	.232
Douglas-fir	27.5	27.4	.19	.188
Subalpine fir	20.0	3/	3/	.260
Grand fir	21.2	37.4	.20	.353
Western larch	30.0	24.3	.24	.194
Western hemlock	26.8	31.2	.18	.207
Western redcedar	20.6	23.1	.15	.168
Engelmann spruce	21.2	30.6	.19	.274
Whitebark pine[4/]				

1/ $(d_o^2/d_i^2) - 1$ from equation (1).

2/ R from equation (1).

3/ Considered same as Douglas-fir.

4/ Considered same as western white pine.

TABLE 10.--*Height-d.b.h. relationships for trees from a variety of site indexes and stand densities*

Species	N	Function[1/]	R^2	Standard error of estimate
Grand fir, western white pine	88	$Ht = -30.9396 + 29.5692d^{0.5457}$	0.9607	9.5753
Douglas-fir, ponderosa pine, subalpine fir	82	$Ht = -38.4256 + 37.0809d^{0.4167}$	.9112	10.3924
Western larch, western hemlock	87	$Ht = -43.6855 + 42.3829d^{0.4387}$	.9328	11.025
Western redcedar, Engelmann spruce	71	$Ht = -26.2339 + 26.1048d^{0.5224}$	.9506	8.8539
Lodgepole pine, whitebark pine	51	$Ht = 327.7645 - 333.5225d^{-0.1124}$	.9244	5.1944

1/ d = d.b.h., in; Ht = height, ft.

TABLE 11.--*Fractions for partitioning weights of small trees and unmerchantable tips into 0- to 1-in, 1- to 3-in, and 3+-in size classes*

Top diameter (in)	Size class (in)	Tree d.b.h. (in)					
		1	2	3	4	5	6
3	0 to 1	0.079	0.037	0.035	0.029	0.046	0.026
	1 to 3	.921	.963	.965	.971	.954	.958
	3+	0	0	0	0	0	.016
4	0 to 1	.078	.032	.016	.011	.015	.010
	1 to 3	.914	.826	.444	.375	.325	.393
	3+	.008	.142	.540	.614	.660	.597
6	0 to 1	.078	.032	.012	.006	.004	.003
	1 to 3	.914	.826	.308	.196	.118	.099
	3+	.008	.142	.680	.798	.878	.898

TABLE 12.--*Total tree volume equations from Stage's (1973) Growth Prognosis Model*

Species	Equation[1/]
Western white pine	$V = ((0.002403d + 0.001391)h - 0.0001305d^3)d$
Lodgepole pine	$V = 0.002782 \text{ EXP}(1.9041 \ln(d) + 1.0488 \ln(h))$
Western larch	$V = (0.002088h - 0.000123d^2)d^2$
Western hemlock	$V = ((0.002742h - 0.00358d)d + 0.0386)d$
Grand fir	$V = (0.002554h - 0.0000758d^2)d^2$
Western redcedar	$V = (0.002458h - 0.0001646d^2)d^2$
Engelmann spruce, Douglas-fir, Subalpine fir	$V = (0.001714d + 0.003865)dh$
Ponderosa pine	$V = (0.002474\ d^2h - 1.5571)$ If $d^2h \leq 6000$, $V = 0.002213d^2h + 0.030288$

1/ V = volume, ft^3; d = d.b.h., in; h = tree height, ft.

TABLE 13.--*Fractions of merchantable live tree bolewood that are defect averaged from data on Clearwater and Coeur d'Alene National Forests*

D.b.h. (in)	Species									
	Ponderosa pine	Western larch	Grand fir	Western white pine	Subalpine fir	Douglas -fir	Western hemlock	Western redcedar	Engelmann spruce	Lodgepole pine1/
2- 6	0	0	0.06	0.02	0.04	0	0.01	0	0	0
7- 8	0	0	.06	.02	.04	0	.01	0	0	0
9-10	0	0	.07	.02	.04	0	.04	0	0	0
11-12	0	0	.08	.02	.05	0	.06	.01	0	0
13-14	0	0	.08	.03	.05	.01	.09	.03	.01	0
15-16	0	0	.08	.03	.06	.01	.12	.05	.03	0
17-18	0	.01	.09	.03	.06	.02	.15	.07	.04	0
19-20	0	.01	.09	.04	.06	.02	.17	.08	.06	0
21-22	0	.01	.10	.04	.07	.03	.20	.10	.07	0
23-24	.01	.01	.10	.05	.07	.03	.23	.12	.08	0
25-26	.01	.01	.11	.05	.07	.04	.26	.14	.10	0
27-28	.01	.01	.11	.05	.08	.04	.28	.15	.12	0
29-30	.01	.02	.12	.05	.08	.05	.31	.17	.13	0
31-32	.01	.02	.12	.06	.09	.05	.34	.19	.14	0
33+	.01	.02	.13	.06	.09	.05	.37	.21	.16	0

1/ Whitebark pine considered same as lodgepole pine.

TABLE 14.--*Contribution of debris for tree history codes used to classify trees for timber stand inventories in the Northern Region*

Tree history code	Definition of trees	Fraction of tree component that is actually debris				
		Foliage	Branches	Tops	Boles	Bark
1	All live merchantable trees	1.0	1.0	1.0	1.0	1.0
2	Live cull <5 inches d.b.h.	1.0	1.0	1.0	1.0	1.0
4, 6	Sound dead ≥5 inches d.b.h., dead more than 5 years, 50 percent or more sound wood	0	.4	1.0	.5	0
5	Sound mortality ≥5 inches d.b.h., dead 5 years or less, 50 percent or more sound wood	1.0	1.0	1.0	.5	1.0
7	Nonsound dead, any d.b.h., and sound dead <5 inches d.b.h.	0	.4	1.0	1.0	0
8	Live cull ≥5 inches d.b.h., less than 50 percent sound	1.0	1.0	1.0	1.0	1.0